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Mapping whose reality? Geographic information systems (GIS) and "wild science"

Sally L. Duncan

In taking the landscape-scale view increasingly demanded of natural resource management, scientific assessments make considerable use of geographic information systems (GIS) maps to convey the research findings they develop. Public interaction with scientists over natural resource management issues is therefore frequently mediated by such maps, which can directly influence how the landscape is viewed, and how science findings are communicated and understood. Analysis of the Coastal Landscape Analysis and Modeling Study (CLAMS) project in western Oregon reveals that GIS maps play a significant role in how we frame and address natural resource management issues. They can support the role of privileged knowledge as held by the map makers, typically scientists, and may reinforce it by the de facto "map tyranny" that gives primacy to scientific worldviews. But they can also enable broader kinds of inquiry through multiple frames of reference, enhancing story-making opportunities for stakeholders. Which of these trajectories is followed is affected by resource availability and new perceptions of responsibility, each of which reflects social power structures. The CLAMS case study suggests that map user/non-scientists appear less likely to be victims of "map tyranny" the more familiar they are with the technology. Accordingly, they become more likely to push for usable results from it, and more confident about engaging their own knowledge with that of the map maker/scientists.

1. Introduction

Science and scientists were not always an assumed part of natural resource management. Until the revolutionary US environmental legislation of the 1960s and 1970s, which helped generate the litigious 1980s and 1990s, scientific research in natural resource policy development was regarded as "occasionally useful and generally harmless" (Jerry Franklin, in Johnson et al., 1999: xi). Science tended to be seen as the means to improve existing practices, but rarely as worthy enough to question basic policy assumptions.

However, once Rachel Carson's *Silent Spring* was published in 1962, and the National Environmental Policy Act began a legislative shake-up in 1969, the trajectory to be followed by science in the interest of natural resource policy changed permanently. Scientists started

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showing up in courtrooms, at Congressional testimony, at public and private meetings with agency and resource professionals, and at public meetings involving stakeholders. Few continued to believe, after the mid-1980s, that natural resource policy could be forged without incorporating the best and most current available science (Johnson et al., 1999). What was dubbed "wild science"—the probing of basic assumptions underlying current policy—was not only becoming acceptable, it was soon aggressively sought after in these multiple venues. During the same period, the scale at which natural resources and their associated ecosystem processes were viewed was increasing by orders of magnitude as the concept of ecosystem management gained a secure footing.

In this turbulent social setting, the arrival of Geographic Information Systems (GIS) technology as a means for analyzing spatial data, and shortly thereafter as a means for displaying the results of those analyses, appeared highly likely to introduce significant shifts in the map-making world. It has been heralded as a "democratizing" technology (e.g. Mark, 2000; Jankowski et al., 2001), potentially allowing hands-on interpretation of data by all, but the reality has turned out differently, and constraints on time and resources typically put the data-based decisions in the hands of scientists. The maps they churn out adopt a kind of tyranny: it would be easy for the uninitiated to ascribe to them the same level of "truth" one imparts to a map on a road trip.

But just as scientists had begun to question the accepted wisdom of public resource managers, so stakeholders and attentive publics have begun to question the assumptions of scientists. And their data. And their objectivity (e.g. Priest, 1995; Fischer, 2000; Benda et al., 2002). At the same time, the multiple and ongoing disagreements among scientists themselves as they undertake the challenging process of researching new ideas have become more public than they have ever been. Increasingly therefore, we hear interested publics ask of the GIS maps used as tools in natural resource management, mapping whose reality?

Adaptation of and to technology involves social choices, and shaping technology use and the discourse around it can be a complex and conflict-ridden process. GIS is now sufficiently embedded in the environmental science arena to influence how we use and consider environmental data. Thus our central research questions are: in what ways does GIS affect the framing of environmental issues in natural resource decision-making? How does the use of GIS maps and databases affect existing power structures?

The exploratory case study used to address these questions examines GIS maps from the Coastal Landscape Analysis and Modeling Study (CLAMS), a landscape-scale bio-regional assessment that draws heavily on GIS technology to illustrate ecological and socioeconomic dynamics and interactions. CLAMS encompasses the Oregon Coast Range Province, a 5-million-acre area stretching from the northern border of Oregon, almost to its southern border with California, and west from the crest of the Coast Range to the Pacific Ocean. Combining data collection from remote sensing and field plots, the CLAMS science team has developed multiple models (vegetation, wildlife, land use change, policy outcomes), and displays much of its data in the form of GIS maps.

The CLAMS project grew out of political and social turmoil surrounding the development of the Northwest Forest Plan under direction from President Clinton in 1994, and the desire of scientists to develop a more responsive set of models to do anticipatory assessments. Although public interaction was not initially a planned part of CLAMS, it has evolved piecemeal as the study developed, including large landowners, the state, and federal managers initially, and subsequently smaller landowners and watershed councils. Both small-group interactions with specific stakeholders, and large public meetings have informed the CLAMS public involvement process, which has yielded useful insights into knowledge creation.

2. GIS: data or design?

> Like the universal fascination with moving water, or the dance of a fire's flame, maps hold some primal attraction for the human animal. (Aberley, 1993: 2)

The problem with maps is that we think we know what they mean. As universal social icons, surely, they tell us where things are, how they relate to each other, and give symbolic representation of what they will look like if we ever go there. But what happens when our assumptions as map users don't match those embedded in the map by the map maker? At that point, are other people biasing our worldview with their own construction of the knowledge we use to tackle environmental problems? For GIS map-making requires making weighted decisions on ". . . what to measure, what to count (enumerate), what to feed into the model. And every one of these decisions or assumptions is also always a decision about what counts" (Sandercock, 2004: 136).

Conflicting viewpoints on the value of GIS use have emerged since the technology was developed. Many of its reported benefits arise from its technical applications: efficiency gains in data handling, increases in cartographic and analytic capability, improved visualization and communication of spatial information, and allegedly enhanced decision-making (Sieber, 2000a). It is also noted that GIS supports both exploratory and confirmatory analyses, both inductive and deductive approaches, as well as both scientific research and the implementation of public policy based on GIS models, a nod to its social potentials (Mark, 2000). Mark led a team investigating issues of scale, integration, process models, and usability, then focused on particular challenges arising in representation of geographic data in binary mode. In particular, the team found that GIS lacks the dimensionality and temporality that environmental problems require, and has only a questionable ontology of reality at geographic scales. He asked, how do we summarize, model, and visualize differences between digital representation and real phenomena? In particular, Mark noted, simulation is in its infancy, so issues of usability of systems and technologies lack a theoretical base.

Jankowski and colleagues (2001) observe that for experts, the idea of a GIS map was chiefly that of a convenient tool for checking the output of their models against their expectations. They point out that the use of maps as analytical tools in spatial decision analysis has been little explored. Consequently, it is generally acknowledged that accurate data on benefits, or problems, generated by GIS technology are rare (Gillespie, 2000).

Robinson and Petchenik (1976) introduced several key themes three decades ago, of which the most pertinent here is that maps are tools of communication. Arguing that mapping derives from systems of assumptions, logic, human needs, and human cognitive characteristics, they deduced that as cartography increases in complexity, the analytical and intuitive effort needed to produce successful maps will increase. Other scholars emphasize the cultural embeddedness of mapping; maps lend order to the world, not least by materializing a way of experiencing (Rundstrom, 1990; Geertz, 1976). Thus we can conceive of mapping as acting, as opposed to merely recording, and Rundstrom stresses the importance of maps as intracultural communication tools.

Tufte (1983) comments on data maps in general that we tend to focus rapidly on the substantive content of the data, rather than on the methodology and techniques that have produced them. He also notes the increase by orders of magnitude of data density since the time early maps of earth and sky were created and agreed upon. Those who accept complex GIS maps at face value, therefore, are accepting increasingly large quantities of invisible data. One powerfully descriptive graphic depicts a GIS map as the superficial visual tip of a very large database iceberg (Schuurman, 1999). Sismondo and Chrisman (2001) question the scope and value of realist construals of maps, and by extension those of scientific representations. They call for further investigation of how the idea of maps varies with perspective, context and metaphor.

GIS has long been decried as “ontologically shallow” and insufficient to the task of comprehending the many epistemological points of difference among users, students, and creators of GIS (Schuurman, 1999; Taylor and Johnston, 1995). In this context, Pickles (2004) contends that the contingent nature of technical outcomes from GIS use is often overlooked, and the exploitation of some groups, particularly those with less access to technology, becomes a real possibility. He also emphasizes how important it is “to study maps in human terms, to unmask their hidden agendas, to describe and account for their social embeddedness and the way they function as microphysics of power” (Pickles, 2004).

The ongoing discussion of how GIS might affect knowledge production, and the resulting relations between producers and users of knowledge, is illuminated by a study of communication barriers in the natural resource arena, asking what non-scientists hear when scientists speak (Weber and Word, 2001). Information is often seen by both parties as a transmission process: one way, and finite. But communication is an ongoing process, involving negotiating meanings, interpreting messages, dealing with responses and misunderstandings; public discourse in particular reveals the conflict that results when multiple frames of reference vie for notice.

Behind these discussions lurks the shifting role of science in society. The primacy of science as the apparent informant of policy decisions is under siege. Fischer (2000), for example, notes that we are privileging an elite to make decisions that don’t always affect them personally. As the types of decisions to be made become more complex, just as the concept of public involvement and collaborative decision-making become more prominent, Fischer poses the question this way: can democracy thrive in a complex technological society? To further complicate matters, publicly expressed concerns about science rarely encompass just the science itself, often addressing as well the institutional and political issues surrounding it (Priest, 1995; Funtowicz and Ravetz, 2001).

Kasemir has found that scientific researchers do not inherently have the capacity to frame the dimensions of an environmental problem in ways the public will understand (Norton, 1998; Kasemir et al., 2000), although other researchers point out that neither do they completely lack this capacity, as advocates of “value-neutral” science seem to suggest (Gethman, 2001). Correctly framing the problem begins to place GIS maps in the position of serving, if used intentionally, as conflict resolution tools (Bojorquez-Tapia et al., 2001; Hillier, 2003; Fall et al., 2001). This compelling perspective on a technology originally designed as a spatial analysis and digital presentation medium is supported by findings from an experiment on collaborative decision-making using GIS (Jankowski and Nyerges, 2001). Noting variable use of GIS maps during phases of decision-making, the researchers also observed that the exploratory-structuring phase had low conflict, and the analytic-integrating phase had high conflict. They conclude that GIS maps in the role of conflict management could conceivably help work through it.

Just as important, these maps are being conceived around the world in new roles as prisms for alternative forms of knowledge, including traditional ecological knowledge (TEK), local knowledge, and environmental narratives (Kyem, 2004; Dunn et al., 1999; Puri and Sahay, 2003; Ceccato and Snickars, 2000). The important point here is that as the technology diffuses, its uses and meanings continuously and interactively change and adapt.

And this is instructive for our research questions: technologies such as GIS are socially constructed, meaning they do not get created then exist in a vacuum without response from the world they have invaded. The idea of technological determinism made famous by McLuhan (1964)—we shape our tools and they in turn shape us—is coming back into vogue perhaps because its practical and theoretical implications are now more daily before us. He asked, does a tool-using culture let its tools intrude on its beliefs and values? If indeed we have become a "technopoly" (Postman, 1992), a society whose thought-world is monopolized by technology, Postman believes we are at risk of seeking our authorization from, finding our satisfaction in, and taking our orders from technology. Pickles (1995) supports the idea that maps have always been precursors to exploitive behaviors: they chart and stake a claim to new territories, by wealthy investors, in a world that undeniably can be shaped, manipulated, and acted upon.

Most technology diffusion researchers agree that adaptation to technology occurs in phases. One proposed path includes awareness, interest, evaluation, trial, and adoption (Brunn et al., 1998). Another posits knowledge, persuasion, decision, implementation, confirmation, with the middle three highly dependent on potential users' being influenced by and learning from current users (Rogers, 2003). Along the way comes the need for change, at both the macro (organizational) and micro (individual) levels (Beard, 2002). Such change raises questions of societal values and of dependence and dominance (Masser, 1996), and it is also crucial to consider that diffusion variables are highly interactive: no consequence of GIS use in either the science enterprise or public participation acts in a vacuum (Wejnert, 2002).

Rohracher (2003) has observed that the social shaping of technology can be a long-term, interactive, and sometimes conflict-ridden process. Indeed, Sieber (2000b) found among the grass-roots organizations she researched that they routinely apply GIS to goals loftier than efficiency, such as the transformation of meaning. Sieber's reinterpretation of GIS as agent of change suggests it could also become a changed agent, under changed power structures.

Posing technologies as boundary objects that continuously mediate expectations, Rappert (2001) observed that other factors and effects include control of information, asymmetrical knowledge, marginalized expertise and learning, and the construction of individual narratives in order to make sense of the day-to-day use of technology. The exclusion of certain groups from decisions, whether through lack of resources or through their own disinclination to become active, can directly affect the resulting structure of environmental problem-framing.

Some thinkers have decried GIS as crossing moral and ethical lines we should not trust, the "big brother" image flickering in the background. Most glaringly questionable in this context is the prevalence of monopolistic software providers with formalized rules and standards, the cost of hardware and software, and the difficulty in learning how to analyze and model complex relationships without full knowledge of how to use GIS (Curry, 1998). Designed around a dominant style of thinking, such a technology inevitably discards important elements of the sense of place, reducing them to the "detritus of calculations."

Rather than pursue a single-minded goal of continued tool development, Nyerges and colleagues (2002) make the case for a reconstructivist perspective on the social-behavioral implications of tool use. Clearly, GIS technology is here to stay, but tool use within organizations and their bureaucracies raises questions of structure and meaning in planning situations. The social norms that guide such tool use, and the problem-framing it helps to address, will doubtless repay critical evaluation.

Participatory GIS, or PGIS, raises some associated questions. A number of researchers have asked, can GIS provide the kind of empowerment that transfers control over decisions and resources to communities and extra-governmental organizations? Kyem (2004) notes that having empowerment as an ideal outcome sets PGIS apart, and generates an urgent need for further critical review of ongoing and completed projects in order to better understand the implications of technology-based empowerment in this modern context. “Communicative action” in conjunction with GIS in a case study in India is seen by Puri and Sahay (2003) to be crucial to real empowerment, but they stress also the key role of individuals, suggesting the tenuousness of any long-term connection between GIS and the breaching of existing power structures. Barrett and others (2001), in another study from India, posit stability, reflexivity, and the concept of trust systems as essential to supporting successful empowerment interactions between new groups of people and new networks surrounding introduction of the technology. Not all of these social aspects of a setting in which GIS is applied are always in place, or even available, however.

In the United States, several representative studies of GIS used in local settings focus on the organizational context and institutional cultures affecting them (Norheim, 2004; Elwood and Ghose, 2004). Elwood and Ghose seek to expand the understanding of organizational effects on PGIS projects beyond the internal capacities of the project itself, to include local networks, organizational knowledge and stability along with its mission and resources; their aim is to further theorize the importance of local political contexts in the effort to improve understanding of constraints upon community empowerment. Ghose (2005) has subsequently confirmed that in inner city PGIS, the planning process contains a number of barriers to participatory planning, including a more technocratic approach. She finds, nonetheless, that participants typically do learn the navigational skills required to create opportunities to change their urban space through PGIS.

Norheim’s (2004) study of two competing GIS treatments (one agency, one non-governmental organization) of an environmental issue in the Pacific Northwest indicates that institutional culture can directly influence map production, and suggests that even if community groups are empowered to produce their own maps, the breaching of surrounding power structures may not in fact be inherent to GIS use itself, but rather to *what happens next* to the new knowledge a GIS activity creates. Knowledge management, an increasingly complex component of developed and developing countries, itself demands cultural transformations in learning skills, most particularly when the nature of the problem to be addressed, as in environmental issues, is multi-disciplinary (Fischer and Ostwald, 2001).

It does seem that substantive and particularistic details of the context may not be a strong factor in the development of power structures in the PGIS process. Social and organizational psychology suggest that through sharing problem perspectives and working with different kinds of knowledge and experience, multiple actors/stakeholders construct together a new social learning practice (Bouwen and Taillieu, 2004). The collaboration required by a successful PGIS process acknowledges that the technical complexity and social embeddedness of natural resource management issues render simple planning/implementation approaches obsolete, and Bouwen and Taillieu’s findings suggest that the central concerns for PGIS are indeed power relationships:

> An indication of the success of the interaction among the stakeholders is the emergence of a negotiated order, where all parties can find some place. [These] can be bilateral agreements, or in the best case, a multi-lateral arrangement for sustainability and reflection. (2004: 149)

Thus we find the nature of the technology itself, entwined with the characteristics of the technocracies that embrace it, tending always to support existing power structures (Kyem, 2004; Dunn et al., 1999). For example, “community-based PGIS organizations are resource poor and often need to conform to pre-set data standards of software models and to the views and dictates of external experts" (Kyem, 2004: 6), and "GIS has to date served the interests of the 'upper circuit' of knowledge, which is dominated by urban-based, formally educated, instrumentally-orientated elites, with the ability to make capital-intensive investments to reproduce and further enhance their initial advantage" (Dunn et al., 1999: 328).

Dunn et al. (1999) are now concerned that in training the next generation of technical elites from lower-income countries in GIS, we are binding in them the characteristics of a medieval guild, strongly supportive of the power arrangements currently in place. Elwood and Leitner (2003), however, examined the conflicts between state priorities and local visions in the use of GIS, finding that GIS can indeed serve as a mechanism through which the state can essentially incorporate community organizations into its planning service system. But they also identified an opposing trend, in which local, or "non-codified" spatial knowledge was able to advance alternative interpretations of local space without merely conforming to state planning goals.

The social constructivist perspective suggests that environmental problems are framed in a dynamic context, in which "environmental issues are seen to be constantly 'rising and falling in prominence' as a result of their construction and reconstruction by individuals, organizations, and institutions" (Cosio, 1998: 369). The very nature of GIS technology, with its powerful spatial data analysis capabilities, and the capacity to produce multiple maps from the same database, supports precisely this rising-and-falling, construction-and-reconstruction challenge of defining environmental problems for natural resource management. Other social constructionist authors (Gergen, 1983; Shotter, 1993) and knowledge discourse scholars (e.g. Brown and Duguid, 1996; Fischer and Ostwald, 2001), now tend towards a "knowledge-as-participation" metaphor, in which the creation, sharing, and development of knowledge are essentially relational.

Thus we have conflicting ideas on whether the privileged knowledge of the state (in the current study perhaps represented by research scientists) directs our approach to natural resource management problems. The questioning capacity of GIS and the public's increasing familiarity with it does seem to open doors to new forms of knowledge community.

> Maps break down our inhibitions, stimulate our glands, stir our imagination, loosen our tongues. The map speaks across the barriers of language . . . (C. Sauer, cited in Robinson and Petchenik, 1976: 2)

3. Methodology

For this study, transcribed focus group sessions were subjected to content analysis using N4 software, and were considered in light of analysis of other datasets in a larger study. Participants in the focus groups were attendees at a 2004 research workshop, selected from attendees at a workshop two years previously, to represent the same heterogeneous population (i.e. people familiar with CLAMS) in similar proportions. Attendees included seven CLAMS team members (CLAMS Ecologist 1 and 2, CLAMS Economist 1 and 2, CLAMS Fish Biologist 1, and CLAMS GIS Specialist 1 and 2) as well as representatives from one forest industry corporation, one non-industrial forest, two watershed councils, two non-governmental organizations (NGOs), two federal agencies and one state agency, and a tribal confederation (quoted respectively below as Industrial Forester 1, Non-Industrial Forester 1, Watershed Council Coordinator 1 and 2, NGO Representative 1 and 2, Public Lands Manager 1 and 2, State Agency Representative 1, and Tribal Manager 1). The non-

CLAMS participants were selected to represent, broadly, the stakeholder groups already using CLAMS databases and maps, and likely to continue using them in the future.

Questions posed to the participants during focus group discussions derived from preceding data analysis. They included: what is a GIS map? What are the elements of trust between map makers and map users in GIS? What new ideas and powers does GIS bring to the table? What unintended consequences emerge from GIS technology? How do we go from the abstract to the concrete in using GIS maps? How are GIS maps useful in mutual learning and conflict resolution?

Content analysis involves the coding or categorizing of bodies of text into themes or clusters of meanings, in order to understand patterns, relationships, sequences, or differences. Codes can refer to settings, definitions, perspectives, events, processes, strategies, relationships, and methods, for example. Codes can then be clustered to understand larger patterns. In this case, coding was done without creating categories, or themes, from a priori knowledge, and it was frequently in vivo, deriving labels from actual words used repeatedly by focus group participants (Strauss, 1987).

Ultimately, focus group data sorted themselves into 23 categories (see Appendix). From these categories, four main clusters were established: Effects of Clashing Epistemologies, Effects of Alternate Story-Making, Shifting Learning Goals, and Process as a Tool of Change.

In the resulting diagram of codes (Figure 1), within each cluster, codes were placed as closely as possible to those they directly affected, but cross-cluster links also became important, and could not always be illustrated by adjacent placement. The idea of indirect links between clusters—manifested by multiple and cross-cluster coding—underscores the tight coupling and interaction between this code structure and the links to theory established in discussion and conclusions.

4. Results and discussion

To set the context, a brief selection of the commentary by a cross-section of focus group participants of what GIS “does” and “brings” to natural resource management is provided here:

> It’s a representation of somebody’s view of what reality is, so it’s an expression of that idea, and it happens within GIS to be able to be displayed in a variety of different ways so you can express a variety of different ideas.

> One mode of communicating the results of models.

> The technology makes map-making more accessible to a greater number of people. You still end up with a map.

> It’s not just a map of information, the GIS part allows you to combine different themes to produce a new map that you couldn’t get very easily some other way.

> What I think is emergent is the capabilities of the system to allow the asking of questions and the contemplations of kinds of analyses that no one would have tried without the tools.

> From a research perspective it allows you to learn what the outcomes of the relationships are more quickly than you would be able to do without that technology, so your learning capabilities are greatly enhanced.

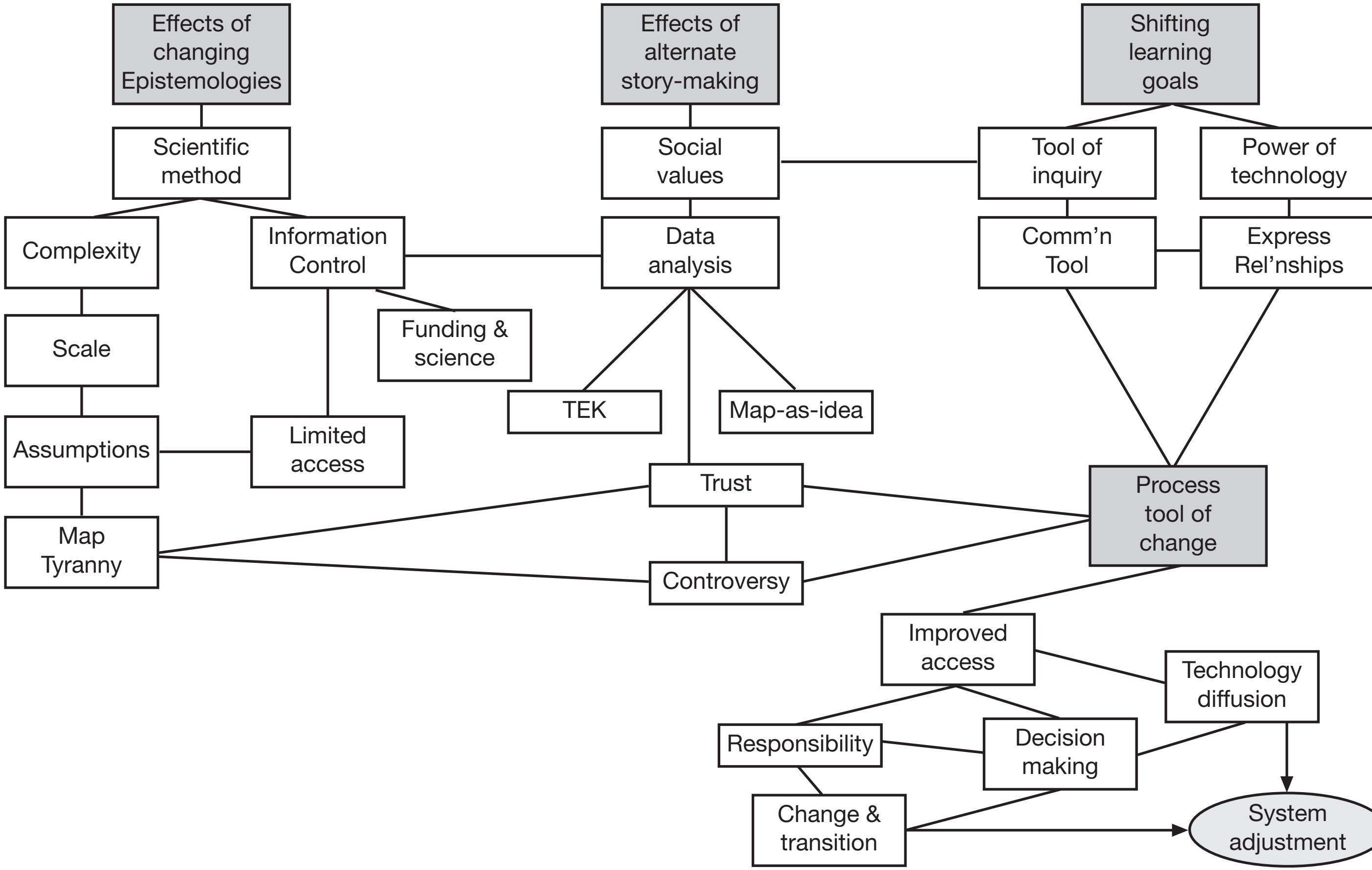

Figure 1. Themes in content analysis. Codes clustered around four key themes—Effects of Clashing Epistemologies, Effects of Alternate Story-Making, Shifting Learning Goals, and Process as a Tool of Change—and can contribute ultimately to System Adjustment (social change) in the dynamic arena of using GIS maps in natural resource management.

In content analysis of focus group discussions, coding categories fell into four key clusters—Effects of Clashing Epistemologies, Effects of Alternate Story-Making, Shifting Learning Goals, and Process as a Tool of Change. Taken together, these clusters helped clarify some of the effects of GIS on how we address and define environmental issues.

Effects of Clashing Epistemologies

As deep background to all scientific endeavors, *Scientific Method* emerged early as a code in its own right, as it underlay many of the comments made by scientists/map makers about current challenges, some of which relate back to communication barriers between them and map users.

CLAMS Ecologist 1 commented:

> There are three types of science that are done. One is description, you're describing something, another is looking for association, and another is you're looking for a cause-effect relationship . . . What we're doing here is taking the descriptive and associational work and saying we've looked at the associations for plants, we've looked at the associations for animals, we've looked at the associations for water, we've looked at the associations for people, how do all those things fit together into a hypothesis that integrates among all those things? And then that hypothesis becomes the basis, possibly, for a policy, and if the policy is implemented then that's the beginning of the experiment.

We might immediately ask, how clear is it to map users that a GIS map is merely "a hypothesis"? That any given policy is merely "an experiment"? Although this framing of map-as-hypothesis, and policy-as-experiment, captures the epistemological viewpoint of natural scientists, its approach has not been well understood outside the scientific fraternity (Weber and Word, 2001). Indeed, according to CLAMS Ecologist 2:

> I think we often don't focus on how scientists come up with hypotheses. That whole hypothesis-generating part of the scientific process is often highly subjective, it comes from experiences we've had in various different places, we think, this is my view of how the world works. And this way [GIS map-making] is a more formulated way of generating hypotheses.

The primacy of the scientific method for knowledge-building in natural resources, for formulating hypotheses and establishing the understanding that feeds policy, interacts with *Complexity*, *Scale*, and *Assumptions*, three subsequent components of the Epistemology cluster.

Complexity and its myriad implications is understood best by the map makers who must grapple with it, pixel by pixel. Scientists as map makers are dealing more frequently now with audiences who do not have the tools or the training to comprehend all the complexities to be encountered in landscape ecology, or large-scale scientific assessments such as CLAMS. One possibility, according to CLAMS Ecologist 2, is to reveal the complexity to map users:

> We can document the process that we've used to make these maps but it would fill volumes for all the little decisions that get made that we don't really write down . . . there's a certain energy required to verify the quality of something and if we had to verify the quality in great detail of everything that's out there we'd be totally immobilized trying to make these decisions, so there has to be trust, otherwise the system gets overwhelmed.

Whereas scientists are under a professional obligation to embrace complexity continually when working with landscape ecology and developing GIS maps from the available data, non-scientists must distinguish between issues that need to be understood in all their depth, and others that ask only a passing familiarity. In the words of Watershed Council Coordinator 1:

> Well, the first filter there is how important is the decision, if this is going to be how you're going to proceed for the next 50 years in how you're going to attempt to prevent the extinction of spotted owls then it's worth spending some time and effort on [delving into the complexity]. If this is going to be something a little less momentous, a little more trust is easier.

Grappling with *Scale* in both modeling and data analysis can also be a confounding part of the scientific process that calls on GIS maps to aid in interpretation and problem-framing. CLAMS Ecologist 2 articulated it thus:

> I guess that's the advantage [of using GIS] though, that depending on the question, you can explore the answers to that question at appropriate scales or multiple scales and at multiple scales you probably will get multiple answers to the same question.

Scale will continue to be a challenge for both scientists and non-scientists, and GIS technology allows greater flexibility in how to interact with and display it. This does not alter the fact that primary scale decisions are generally made by map makers, not map users, or that scale representations greatly affect how an area or an environmental problem is perceived.

If scale and complexity are elements of the scientific trade that must be managed by map makers, recognized by GIS technology, and somehow translated for other audiences, then assumptions are surely the "hidden language" of GIS maps. As a stumbling block of some stature, *Assumptions* required its own category.

CLAMS scientists are not insensitive to this problem, and have found themselves frequently explaining assumptions when delivering public talks. As voiced by CLAMS Fish Biologist 1:

> It seems to me that it's incumbent upon the scientists to be as explicit as possible about the assumptions and any other things that are in these maps, [so that] we're just not laying this out there without trying to explain it . . . that then puts the burden on the people who want to use it to understand what the limitations are and what the assumptions are. If you believe the limitations and you accept the assumptions then you can use it.

As in other parts of this study, the request from map users to include assumptions in the GIS map layers is becoming a drumbeat that underscores a key development: the continuing advancement of interested members of the public in their understanding of technical data. In this context, Watershed Council Coordinator 1 raised the possibility that the technology could provide a relatively simple solution that wasn't previously available:

> The other suggestion I would have is at some level with the variables that you think are the particularly important ones, for you to make that part of the presentation. OK this is the variable that if you budget 10% the map really looks different, this is one that's in there but we can put pretty wide swings and it really only tweaks things. That's information that I think is really powerful in getting people to understand what you're doing.

Directly related to *Assumptions*, but in a category of its own, *Map Tyranny* was seen to be capable of wreaking havoc with the best-laid inquiry. Tribal Manager 1 saw it thus:

> I think it's really important that when a product is produced that somewhere it is explained what the assumptions were that made that product and where the information came from. Because to Joe Blow on the street it's a map, and it might not necessarily be portraying what's going on now but they look at it and say oh wow, this is the way it is!

Watershed Council Coordinator 2 described a specific example of such "leading by maps" in the policy arena:

> I can see that map, the spotted owl map, I can see that getting out and going to a bunch of city councilors, metro planners, county commissioners, they've ordered a decade of mitigation, we've got all this great habitat over there and coming into play over the next hundred years, that's a great excuse for us to expand our boundaries and to incorporate more land and to take out of this production and put it into residential and industrial.

These are real fears, sometimes based on real experience, of how policy makers, just like many map users, can be swayed by the highly persuasive visuals emerging from GIS "factories," particularly if the knowledge producers are well-respected. These concerns about the appropriate use of technology in the application of science to policy suggest that the non-scientist/map users involved with the CLAMS project have gained a relatively sophisticated understanding not just of what the technology can do, but of the social processes involved in disseminating findings via GIS. In a sense here they are policing the ways in which GIS could possibly distort the framing of environmental problems, negotiating meaning, and participating in the identified phases of diffusion of technology (Weber and Word, 2001; Rogers, 2003). The concerns about map tyranny also raised several related themes of interest under the Epistemology cluster: *Information Control* and *Funding & Science*.

Information can be controlled by institutional structures, such as when results can take years to get published, or by other limits to access, such as when the initial inquiry process is done, albeit with no evil intentions, behind laboratory doors. Its dissemination can also be affected by decisions about what audiences need. Public Lands Manager 1 commented:

> If it's important you have to think about the audience you're presenting the map to and what it's going to take to make your process transparent as to how you got to it. The more maps are handed out though, the less control you have but in situations where you're just going to work with a small group, you can control that situation as opposed to hosting something on the web where it's going to take a lot of work to set something up that people could determine if it's good information or not.

CLAMS GIS Specialist 1 questioned whether spreading the "control" around would net us more information and thereby contribute to the discussion, or just give everyone the ability to set up maps to show the world the way they want it to be shown. Certainly this latter is a democratizing capability of GIS technology, and could operate to muddy the dialogical waters by starting "map wars," as has occurred in environmental problems previously. How big a problem might this be? Could it contribute to more thoughtful framing of environmental issues? At the very least, the idea reveals the linkage between *Information Control* and the themes of *Assumptions* and *Map Tyranny*.

An alternative viewpoint, again from Public Lands Manager 1, notes another pertinent issue in information control: "Everybody who wants GIS in coming years on the big issues is going to have it and so basically the bar is just going to be raised in terms of . . . the level of discussion and the tools people use on both sides . . ."

Tightly associated with *Information Control*, *Funding & Science* represents a briefly discussed but important theme that conjures institutional structure as an inanimate but active player on the natural resource management scene, and an ever-present potential constraint on how public involvement is managed. Scientists, too, are subject to the vicissitudes of external control, and ecologists in particular are fully aware of how difficult it can be to get innovative or experimental research funded.

On the topic of *Limited Access*, participants mentioned factors ranging from the obscure source or use of data, to the "closed shop" process of peer review, from the expense and technical complexity of software, to the delayed rate of publication of scientific results. Each of these factors—offered across the board by both map makers and map users—has the potential to create substantial separation between map users and map makers in the world described by CLAMS tools. Other research has found that relationships and politics can influence access as much as technological factors (e.g. Elwood and Leitner, 2003; Ghose, 2005). Findings suggest that non-scientists are aware of many of these factors but remain willing and able to continue collaboration despite them. In other words, while various social and economic factors tend to weight the responsibility for framing environmental issues in favor of scientists with access to the technology, a substantial force for broader involvement exists in the minds and actions of involved non-scientists. Their persistence as participants is likely through time to influence power structures acting upon the framing of environmental research.

Effects of Alternate Story-Making

The central theme in this cluster is *Social Values*, specifically *changing* social values. Despite the persistent touting of science as value-neutral, postmodern thinking supposes that it is not possible to construct a reality the way scientific investigation does, without being influenced by your own values, however slightly. Many scientists themselves are coming to see this, and CLAMS Ecologist 1 put it this way:

> I think one thing that we need to think about within CLAMS and some of the other projects is that the products we produce now are designed to provide information to users that reflect societal values today. And if we were able to step back in time to 20 years ago and have the same technology, the products we'd be producing would be very different, because the social values driving those products would be very different . . .

CLAMS Economist 1 noted that changing values are already reflected in certain CLAMS maps:

> There's another map where we show the . . . environmental protection in 1960 and now, and the amount of the landscape that's managed for ecological values . . . When you have to look at the whole landscape, you have to acknowledge that a number of the ownerships are already doing a lot of different things.

This suggests, given the time frame, that the values emerging reflect those of an increasingly science-driven natural resource policy. Will GIS reinforce this trend, or open the debate to a wider set of worldviews? As a piece of this puzzle, NGO Representative 1 raised the values question in another way:

> It strikes me as we become more familiar with them [maps and models] then we will get to the point where we can stop arguing about what is the best available science about these questions . . . then we can make that choice honestly as a society rather than having the various sides either pretend that there's a scientific debate or fabricate

> one when there isn't one. So let's talk about the things that are really uncertainties and a lot of times they're arguing about political and social choices . . .

The *Data Analysis* theme addresses some aspects of these questions, within the story-making cluster. To paraphrase a CLAMS ecologist, we are now capable of producing multiple, layered, empirical, theoretical, and new images of our landscapes—images that we couldn't produce previously without great difficulty—and producing them rapidly. How do these new images of landscape affect our ability to think about managing natural resources? Do new images engender new thinking?

CLAMS Fish Biologist 1 noted:

> The other way of looking at [creating GIS maps] is it's allowing us to take the results and the lessons we learn from them and apply them across the broader plot. I mean that's exactly what's been the intention. You can look at the literature and we took that and developed it, we developed our information with a series of quantitative models and actually applied it . . . so you're taking these ecological concepts that are spatially undefined in our studies and taking the lessons from them and being able to project those lessons across the landscape.

Within the *Data Analysis* arena, two threads from the Epistemologies cluster can be detected again, complicating the story-making process: map-as-hypothesis (*Scientific Method*) versus map-as-truth (*Map Tyranny*) is a conflict that traditionally tends to divide map makers from map users in their understanding of spatial information. The resulting questions are: what happens to data when they are analyzed spatially? Who selects the range of research questions?

Once again illustrating relationships across clusters, *Data Analysis* and *Assumptions* link to each other in a way that is affected also by *Information Control*. In the hustle of truckloads of data and rapid transmission of new maps, have we undermined our ability to think really deeply about those data? Are breadth of vision across the landscape and depth of thought about the issues equally important, and if so, are we serving both masters effectively with spatial displays such as GIS offers?

There may be, as part answer, more room now for creativity in map-making, certainly in terms of content, although it would take something more than GIS to best the fabulously artistic maps of medieval explorers, for example. In tribute to *Map-as-Idea*, CLAMS Ecologist 2 expressed it thus:

> I think [the] idea . . . that a map is an idea is accurate. It's a representation of somebody's view of what reality is, so it's an expression of that idea, and it happens within GIS to be able to be displayed in a variety of different ways so you can express a variety of different ideas.

This meshes with the potential playfulness of GIS technology, as imagined by Industrial Forester 1:

> Wouldn't it be interesting if we could take the brown blob map [showing land use change as a growing brown element] and as it moves from green to brown the laws go away, or the forest practice laws no longer apply, and if we could run that simulation of the laws disappearing and no longer protecting the stream as the brown blob grows? Wouldn't that be very political? But it would be very effective.

These observations remind us that mapping is a cultural act (Geertz, 1976; Rundstrom, 1990), and that access to technology and control of the inquiry can heavily influence the nature of the inquiry.

There may be, with the capabilities of new technology, more room for incorporating other kinds of knowledge into existing or new maps. *Traditional Ecological Knowledge* (shortened to TEK in Figure 1) became a small but necessary theme in considering story-making. To date, it appears, traditional knowledge, whether handed down through generations such as by Native Americans, or more recently experiential, such as by a non-industrial tree farmer, is playing the role of providing a check on the maps' validity, rather than informing the maps with explicit data. Several map users commented that they know, intuitively, whether a GIS map is "right" or not, because they are familiar with the landscape and how it works. They do not accept maps "totally blindly," because they have "background knowledge of how it is." This finding resonates with the idea that traditional ecological knowledge is inherently more "social" than scientific knowledge, and to date has been effectively shut out of the decision realm (Berkes, Colding, and Folke, 2000). It also supports the finding that map tyranny is weakened by increasing familiarity with the technology.

The idea of linking with map users through interactive technologies—possibly gaining access to previously underused bodies of alternate knowledge—could play a role in building that necessary edifice in the natural resource decision-making enterprise: trust.

The *Trust* theme is linked conceptually to many of the others and is affected by a broad suite of factors, according to focus group comments. Among these are: (1) Comfort with the data and understanding of the model: one watershed council coordinator referred to stakeholders' needing to reach a "tweaking comfort level" with models as a necessary condition of developing trust. (2) Personal experience and personal relationships: another watershed council coordinator referred to the "rules of engagement" agreed to between various landowners in how much will be revealed by a map. (3) The level of controversy and the level of crisis: a CLAMS ecologist spoke of "finding the middle ground" between issues so contentious there's no room for new information, and those that are not yet on the political/environmental radar screen. (4) Pressure for information versus pressure for a decision: a watershed council coordinator spoke of the change in attitude towards maps when they're "no longer just a pretty picture" but are being used for real-life decisions. This list is not exhaustive, but gives an idea of the sociological reach of trust issues.

The "black box" plays a role in trust development between unfamiliar parties when the intervening factor happens to be some extremely complex information. As noted by CLAMS Ecologist 1: "The issue of trust is still going to be there, even though the metadata are available for people to dig into. There's still a trust issue simply because of the complex thing that people aren't willing to go into."

While the "black box" aspect of science may be exacerbated in GIS by the sophistication of the technology, it does at the same time produce images—mapped space—that could help unlock that box. CLAMS Economist 2 notes:

> [There are] advantages of [GIS] maps in terms of trust. All science is a black box in some degree, but the results of the black box can be laid out in the context that people experience the world in, which is spatial, and then people can do their own verification.

Here the technology offers a potential barrier to communication, then, that could with assistance become a bridge. A CLAMS GIS specialist spoke of "maximizing the trust that's possible" as a more realistic goal than aiming for complete trust. Nonetheless, participants recognized that the likelihood of trust holding its ground during a crisis is vanishingly close to zero. The point at which trust loses its bridging capacity was addressed by CLAMS Ecologist 2:

> There's really a sort of gradient of visibility in the sense of this type of information, depending on the amount of contention or crisis or urgency, and type of emergency. The more we're in crisis mode the less useful this type of information is.

Issues of *Controversy*, then, may override the capabilities of an anticipatory assessment such as CLAMS. Given increasing proximity to crucial decision-making, trust is also affected by existing power relations. The CLAMS study supports the idea that some non-scientific constituencies are increasingly willing to question accepted science findings (e.g. Priest, 1995).

Shifting Learning Goals

As a *Tool of Inquiry*, GIS maps advance the ways in which we can conceive of our world, enabling information quests from many perspectives, along with a rapidly accessible view of the whole landscape. Shifting Learning Goals, then, is a cluster of themes representing key potentials for change. It might also be termed new perspectives, as the following exchange suggests:

> Watershed Council Coordinator 2: Well, it allows us to . . . ask different questions which tend to be more traditional questions put into a spatially explicit context . . .
>
> CLAMS Ecologist 2: It allows us to see things from perspectives that we didn't . . . it's not unlike a microscope or a telescope in the sense that you can get a new perspective, the tool allows you to see things in a way that you couldn't very easily see with your naked eye.
>
> CLAMS Ecologist 1: From a research perspective it allows you to learn what the outcomes of the relationships are more quickly than you would be able to do without that technology, so your learning capabilities are greatly enhanced.

CLAMS Economist 1 noted that people have "differential levels of information." This suggests that GIS maps could either remain in the role of purveyors of privileged knowledge, or become levelers, by which everybody's knowledge is brought to a similar point by the spatial information they can now share. Just as importantly, the ability of the technology to respond to a far broader suite of questions can enable our thinking to expand beyond traditional borders and roles.

Recognizing precisely the problem of passivity that currently exists in the role of users of CLAMS maps, however, participants discussed the potential for allowing map users to interact with the maps and experiment with variable values and outcomes. Industrial Forester 1 put it thus:

> I think it offers an unprecedented opportunity to go beyond the standard way we present results. The printed maps are great, but . . . the opportunity exists for us to go to small groups or meetings and not bring the map, but bring the computer along and ask what questions do you have, and someone brings up a counterpoint and says well I don't really like this assumption.

The prospect of interactive GIS maps links to the question of how our social values relate to our inquiries. Ultimately, which agent truly frames our environmental issues, the "best available science" or social values? Several threads lead out from this point. One involves learning from the unexpected, as observed by CLAMS GIS Specialist 1:

> I think maps really challenge our expectations. When someone sees a map for the first

> time if it relates to how that person visualizes the world it's like wow this is a great map, whereas if it challenges how they see the world they say what's this stupid map doing? [laughter] And the interesting thing is that if it's not what you expect, the question becomes do you learn something from that? That's almost more where the learning starts rather than if it's what you expected to see.

Another thread relates to the quality of argumentation. Given a broader view across the landscape, given the ability to look at different outcomes of different actions, are we better equipped to discuss alternate futures? Can we improve the quality of argumentation, as the NGO representative suggested, by moving on from arguments about the science to discussions of issues, values, and the future? Thus the *Power of Technology* theme directs our attention towards the short-term capabilities and longer-term effects of perceiving GIS technology as a medium of interaction as much as a medium of presentation. The crucial piece in this scenario, of course, is the access of more people than scientists to the knowledge-creation power of the GIS keyboard.

The analytical power of GIS relates to its ability to express relationships. As a category, *Expressing Relationships* supports the power and communication aspects of the technology. Thematic spatial relationships have otherwise been expressed mathematically or ecologically, rendering them quite obscure to non-scientists. In addition, the projections of future conditions take us "beyond what we can see" and "to the next level." While these features of GIS-based tools trend naturally towards the viewpoint of the map producer, they can also be undermined by trust issues, as CLAMS Ecologist 1 observed:

> The complicating factor is that others can look at [one of our maps] and say yes it makes sense or no it doesn't make sense, but then they have to trust that we've implemented those relationships, they have to trust that we know what those relationships might be. The black box thing becomes darker and larger the farther you get away from actually developing those relationships. It's a tough one.

Scientists, as a group, are relatively new to the practice of communication outside their own fields and peers. New perspectives on knowledge development and knowledge sharing are a central challenge to the practice of science in the post-positivist world, and can easily be set aside as too time-intensive. Until the technology becomes more universally accessible, in both cost and usability, scientists may remain the map makers for some time to come. Perhaps the best hope for non-scientist engagement lies in keeping the pressure on map makers with more and better questions.

Process as a Tool of Change

Spatial analysis does seem to offer an opening to an improved mode of communicating certain kinds of information (e.g. Bojorquez-Tapia et al., 2001; Ceccato and Snickars, 2000). What emerges from the focus group commentary is the clear sense that GIS technology is not going to do this alone, as its original developers may have envisaged. Instead, the process of communicating over a map—even in heated exchanges—becomes, in itself, a tool of change.

Improved Access is a category that embraces several ideas. *Power of Technology* and *Communication Tool* threads suggested that access to information in its spatial form provides access to improved learning and problem-framing opportunities. A watershed council coordinator made the comparison between looking at numbers to understand population dynamics in the old days, versus looking at "geographic sub-units that are much more comprehensive." Utility of information is improved. Even passive use—in the sense of downloading CLAMS GIS data rather than trying painstakingly to produce it independently—was noted as a beneficial form of improved access. The favorite dream of map users remains nonetheless to have the hands-on experience, as noted by several participants.

Technology Diffusion, which has strong social implications, is at play here. A growing sense of understanding the tool on a social level, rather than exclusively on a technical level, is apparent in many comments. Outside of established research institutions, the transition is most typically in the earliest of stages: GIS cannot be a useful tool while map users have not the time to learn it or the resources to train, upgrade, or hire their way to full use (Brunn et al., 1998). It is not unusual for map users to have tried “the new system,” briefly becoming map makers, and abandoned it for time or resource reasons.

Another feature of early transition is that there is not an easy way for GIS map users to know the source of a GIS map; for example it has no professional stamp on it such as a surveyor uses on a plat map, as GIS Specialist 1 pointed out, and thus no “reassurance” for the map user. But at some point, the stage of technology diffusion becomes a moot issue. Public Lands Manager 1 noted this about technology diffusion in general:

> All this has been going on since long before GIS, you could have the same conversation over spreadsheets and charts and . . . making fancy graphs . . . It’s just this new tool and it can be used, misused, the gee whiz factor is there and you gotta deal with it . . .

Regardless of the stage of adoption, improved access is at least possible now by engaging other technologies, and provides a direct link to the themes of *Decision-Making* and *Responsibility*, in which changes in approach to the framing of environmental issues start to be stated explicitly. Questions arise about whether these maps can realistically be used for policy. Should they just be used to organize our thoughts? To formulate hypotheses for researchers? Or to build dialogue? Until they are produced by a broader cross-section of society, thus incorporating multiple viewpoints and power structures, should they be branded as “incomplete”?

Public Lands Manager1—often in the hot seat of natural resource decisions—noted that he saw the agency role as keeping “a level playing field” in terms of making data available for stakeholders, so that decisions could be made on the basis of the best possible tools. It should be remembered that from the map makers’ point of view, policy is essentially the beginning of another experiment on the ground, whereas a map user interested in resource management issues is likely to view a policy as the end point of a struggle, complete with winners and losers. Hence the relationship between mis/trust and decision-making.

The greatest departure in perspective from a CLAMS workshop held two years previously around some of the same themes (Duncan, 2004), was the emerging idea of *Responsibility*, the conscious engagement by scientists with interested publics to learn and understand the information they each need to engage in the public involvement component of policymaking. Comments from NGO Representative 1 and CLAMS GIS Specialist 1, respectively, indicate how *mutual* responsibility might be manifested:

> I think that because anybody who’s going to think critically about this information is going to have to go back to the tables and look at well how did you come up with that, what is that data, how does that model work, what is that stream reach data, what is that veg layer?

> I think the tools really ask people to be savvy, you know just like everything else around us in a culture of information, there’s so much information out there you can fire off 100 maps. I think what it comes down to is people have to say well I’m looking at

> an image and making a contribution. The maps have to start requiring people to ask the question of where it's coming from, is it really saying [this], who made it?

Connecting many threads under the theme of *Change & Transition*, it was observed that taking the time to consider how we think about our scientific and environmental problems, as some scientists have suggested (Benda et al., 2002), before we launch into policy discussions, could be a productive exercise. As Watershed Council Coordinator 2 observed:

> The very act of putting the issue into a spatially explicit framework really reframes the issue and changes the debate. When someone's talking about too much clear cutting or too short a rotation or not enough salmon or whatever, and you can look at that on a map and say OK now here's where your experience is and here's what's going on down here or here's what's going on over there, it will really reframe the debate in ways that are generally positive.

When we re-frame the debate, when we look more closely at how we construct a given environmental problem, the indirect links between *Social Values* and *Responsibility* become yet more compelling. Engagement in the process of change is realized, suggesting a distinctive phase of technology transition, and a potential for change both in how broadly and in what depth we conceive our environmental issues.

5. Conclusions

While tools such as GIS maps can be used to communicate information of selected kinds, they can also serve to teach us about information itself, to suggest how we think about information as we absorb it and turn it into knowledge. GIS technology has allowed improved questioning by ecologists themselves, right at the time they are being challenged by numerous publics in their chosen calling of wild science. Intelligence, here as elsewhere, is less about knowing than about methods of thought, and the use of new technology generates changed perspectives precisely on the methods of thought traditionally engaged by scientists: who gets to question whose assumptions? What effects do the questions we ask during GIS inquiries have on the resultant stories about our landscapes? In other words, how does our framing of questions reflect our worldview, and in turn influence the stories emerging from the maps?

The GIS maps produced in the CLAMS project and others like it reflect large landscapes, and they provide the ability to sort and combine information thematically, thereby to re-frame debates, refine questions, and challenge static ideas. But the task of understanding how to use the technology, and the power of access to it, goes beyond just understanding the complex content GIS maps display. This challenge has helped map makers—frequently scientists or other specialists—think in terms of a new ethics of presentation, a "shared responsibility" for grappling with knowledge creation issues. That they have identified this need themselves supports a number of ideas about the changing roles of science (e.g. Lach et al., 2003; Priest, 1995; Weber and Word, 2001).

A key factor in understanding problem-framing processes in the natural resource arena is recognizing that no one group has a corner on asking the best questions, or formulating the most incisive hypotheses. Indeed, recent research has confirmed, in line with communication theory on information exchange, that sharing and communicating new information unveiled by GIS maps is what will lead to actual learning (Hendriks, 2000). Thus the simple process of verbal interaction across maps drives and shapes the framing and addressing of environmental issues. Nonetheless it remains unclear whether the propensity for collaboration in any given setting is indeed affected by the existing power structure (e.g. Kyem, 2004; Dunn et al., 1999), or whether, as the CLAMS case suggests, these same power structures will themselves be affected as familiarity with the technology generates confidence among non-scientist, map-using stakeholders, to bring their own perspectives to the table.

And the CLAMS case suggests that map users are indeed hungering for continued improvements in the way ideas are exchanged, in the way stories about their landscapes are put together. In western Oregon, they appear to have surpassed the effects of map tyranny as they increase their understanding of GIS technology and its drawbacks. In this context, existing power structures are more likely to flex or adjust at least temporarily in ways that allow input from alternative viewpoints (Bouwen and Taillieu, 2004; Elwood and Leitner, 2003). Thus the process of utilizing GIS technology becomes itself a process of change, involving everything from the language used to the organizational structure of an investigation, and potentially catalyzing whole system adjustments that cascade through time.

CLAMS GIS maps and databases are quite frequently requested by state, federal, and private stakeholders as the best data and display available for their purposes, according to survey data conducted in another part of this inquiry, and personal communications to the author. Although to date the technology remains largely in the hands of map-making scientists, continued use of CLAMS outputs will increase the growing levels of familiarity of map-using stakeholders with both GIS technology in general, and its use in CLAMS in particular.

The question of how GIS will change the way we think about, inquire into, and define the management of, environmental issues across our landscapes relates directly to whether the technology becomes accessible both physically and dialogically across existing power structures. In this respect, GIS technology in a sense offers choices in social trajectory, just as it illuminates and therefore influences options in environmental trajectory. Ongoing research will help us clarify whether it becomes a force for change of existing power structures, is subjugated to their needs, or provides transforming mixtures of both these outcomes.

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Appendix. List of code definitions: concepts contributing to understanding of codes within content analysis

Scientific Method—deeply entrenched effects on approach of Western-trained scientists. CLAMS group may be in a transition phase in trying to move from positivist approaches to postmodern: how do we address different kinds of knowledge, and how do we accord equal status to other ways of framing questions?

Complexity—comprehended in a specific way by CLAMS scientists, whose concern is the amount of time it could take to describe the complexity, let alone just work around it on any given project. They have to deal with complexity pixel by pixel, map users have to take it in one swallow.

Scale—refers to temporal and spatial problems, but can also refer to the scale of the decisions to be made with the help of the tool. Changing the scale of questions improves our ability to look at emergence of different answers at different scales, providing new perspectives.

Assumptions—represent the "hidden language" of GIS maps, and may represent a way through the trust issue. Request for their inclusion in map layers becoming insistent.

Map Tyranny—can act to stop people questioning a particular map and possibly therefore not contributing usefully to policy discussions. Also plays into understanding, or failure to understand, the fact that landscapes are dynamic.

Information Control—in terms of audience levels as well as how information is presented, who has access to both the information and the presentation technology.

Funding & Science—generally constrains access of non-scientists "outside the system" to funding for inquiry; can also constrain scientists within the system, especially ecologists.

Limited Access—commercial considerations (cost of software), time pressure, openness of the peer review process, complexity of relationships or models, and limitations of data. All limitations appear to be circumstantial, rather than deliberate, perhaps suggesting they are institutionalized?

Social Values—reflexively understanding the social values driving the kinds of maps and types of inquiries taking place today, compared with those that might have happened in the past. Also addressing social values within the maps, so that they can be part of the analysis.

Data Analysis—what happens to data when they are analyzed? How does data analysis divide scientists from non-scientists? GIS data analysis adds the power of new layers and combinations, helping us see new aspects of landscapes. Map as hypothesis (scientist worldview) versus map as truth (map tyranny/non-scientist worldview).

Traditional Ecological Knowledge (TEK)—attentive publics come to GIS maps with preexisting maps of how the world looks, and ideas on natural resources sometimes distant from the findings of scientists. So far TEK is playing the role of informing map users of maps' integrity, not yet of informing the map.

Map-as-Idea—does this idea give greater freedom in interpretation of maps? How does map-as-idea relate to map-as-hypothesis? Concept of map magnetism also applies: the ability of maps to pull people in, leading either to map tyranny, or to enhanced dialogue.

Trust—affected by understanding of the model and comfort with the data; personal experience and relationships; the level of controversy and crisis, or the level of pressure for a decision. Trust can be built around taking responsibility for knowledge.

Controversy—could develop a spectrum in natural resources issues from non-interest to crisis, and see where enterprises such as CLAMS fit on that spectrum. What role, if any, do CLAMS maps have in high-pressure policy decisions?

Tool of Inquiry—maps provide new perspectives beyond what the naked eye provides, the combining of data in new, previously unexamined ways; thematic thinking allowed by GIS maps may assist in mutual learning. How do our inquiries relate to our social values? Also includes use of the tool: how it's used, to what end, in what settings. Tool as enabler.

Power of Technology—GIS allows the move from information to themes, relates to how people more typically process information? How does it therefore open opportunities for mutual learning? Is the technology an enabler? A constantly improving set of tools? "A more formulated way of generating hypotheses"?

Communication Tool—can be used to communicate selected information. Can also be used to teach about itself, how to think about information. How well are we using GIS to teach ourselves ways of thinking? Scientists are new to the field of communication and distinguishing among audience levels; agency people are used to thinking in terms of control of information.

Expressing Relationships—relates to thematic thinking and schema theory. Tool has allowed us to take scientific investigation into a new realm, spatial thinking and perception. Projections take us "beyond what we can see" and "to the next level." What does spatial representation do for us that tabular or other graphical representation did not? And vice versa?

Improved Access—applies to data, technology, knowledge, and learning capabilities. How do we measure impact of improved access? People not used to dealing with maps as such powerful tools. Relates to responsibility.

Technology Diffusion—attitudes toward new technology stay grounded in practicality, functionality, seeing the technology as merely a tool. It might be faster, prettier, but it still needs to be understood as something that can help us with decision-making. Phasing of diffusion influenced by numerous social and technical variables.

Responsibility—need for an interactive relationship? Scientists appear to be asking people to come into their parlor, and help frame the questions; second-guessing isn't working any more. Non-scientists asking for the same thing—in what ways can joint responsibility be structured, then institutionalized, without losing its flexibility?

Decision-Making—where/how does this kind of technology fit in the spectrum of tools available for natural resource management decisions? Can these tools be used for policy? Or should they just help organize our thoughts, or help build dialogue? Given that there is no rational decision-maker, how do we answer these questions?

Change & Transition—links to responsibility, societal values, reframing the debate, new technology and its capabilities; moving from Mylar to pixels. Responsibility of map users to become "attentive public." How might we create an attentive public? Links to concepts of landscape, changing views of science, schema theory, changing social theory.

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